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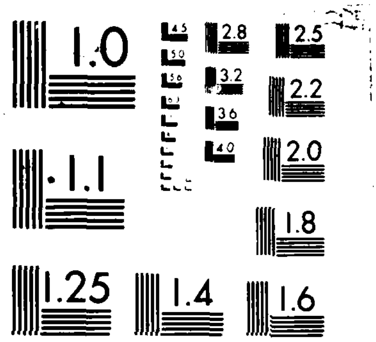

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AFWAL-TR-86-2084
Phase I

FAULT TOLERANT ELECTRICAL POWER SYSTEM

Phase I: Study

Mark W. Dige
Patrick J. Leong
David L. Sommer

Boeing Military Airplane Company
P.O. Box 3707, M/S 33-03
Seattle, WA 98124-2207

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AEROPROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-6563

NOTICE

This technical report has been reviewed and is approved for publication.

JOSEPH A. WEIMER, Electrical Engineer	Lowell D. Massie LOWELL D. MASSIE, Technical Area Manager
Power Components Branch	Power Components Branch
Aerospace Power Division	Aerospace Power Division
Aero Propulsion Laboratory	Aero Propulsion Laboratory

FOR THE COMMANDER

JAMES D. REAMS, Chief
Aerospace Power Division
Aero Propulsion Laboratory

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This report documents the results of Phase I, Study, of this five phase program. The objectives of this program are to develop an FTEPS design for an ATF aircraft and to design and fabricate a low cost FTEPS demonstrator with an integrated load simulator. The primary purpose of the program is to develop an electrical power generation and distribution system that can supply electrical power to the various critical systems on the aircraft with a reliability and power quality level commensurate with the requirements of the loads. In Phase I, the electrical loads and their power requirements were defined for the ATF baseline aircraft model. The loads were also located in the baseline aircraft model.

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22a NAME OF RESPONSIBLE INDIVIDUAL: Joseph A. Weimer

22b TELEPHONE (Include Area Code): (513) 255-6235

22c OFFICE SYMBOL: AFWAL/POOC-1

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SUMMARY

This interim technical report presents the results of the study phase of the Fault Tolerant Electrical Power System program.

In this phase, the electric loads and their power requirements were defined for the ATF baseline aircraft model. The total connected load for the aircraft is 176 kva. This represents 126 loads. 41 kva is flight critical and 123 kva is mission critical. For flight critical loads, maximum power interruption times, which the load can withstand, were established. For many of the digital processors, these times were on the order of 50 microseconds. Some flight control actuators, can withstand power interruptions on the order of 1 second. The electrical loads have been located in the baseline aircraft model. The load list includes loads considered "high technology". These are the electric driven vapor cycle machine in the ECS and the electro-hydraulic flight control actuator called integrated actuator packages (IAP).

PREFACE

This Interim Technical Report presents the results of work performed by the Boeing Military Airplane Company, Seattle, Washington under Air Force Control F33615-85-C-2504. The work is sponsored by the Aero Propulsions Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Mr. Joseph A. Weimer, AFWAL/POOC-1 is the project engineer.

This document, which covers Phase I, Study, fulfills the requirements of CDRL item number 17.

The program manager is I. S. Mehdi. This report was prepared by Mark W. Dige, Patrick J. Leong, and David L. Sommer.

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LIST OF ABBREVIATIONS

AMAD	airframe mounted accessory drive
CNI	communication, navigation, identification
DISAC	digital integrated servoactuator controller
ECS	environmental control system
EMI	electromagnetic interference
EMP	electromagnetic pulse
GOX	gaseous oxygen
IAP	integrated actuator package
IIRA	integrated inertial reference assembly
INEWS	integrated electronic warfare system
IPU	integrated power unit
IRST	infrared search and track
ITM	integrated test and maintenance
LRM	line replaceable module
LRU	line replaceable unit
MAS	mission avionics system
MSIGG	molecular sieve inert gas generator
TF/TA	terrain following, terrain avoidance
VMS	vehicle management system

1.0 INTRODUCTION

The two objectives of this program are to produce a low-cost FTEPS design for an ATF aircraft and to design and fabricate a low-cost FTEPS demonstrator with an integrated load simulator for an ATF. The purpose of the program is to develop an electrical power generation and distribution system that can supply electrical power to the various critical systems on the aircraft with a reliability and power quality level commensurate with the requirements of the loads. Faults in the electrical system can and do occur due to various reasons. Adequate protection and controls to prevent propagation of these faults within the system need to be incorporated such that other normally operating electrical power channels are not effected.

Future aircraft are incorporating advancements in digital computer technology for more and more of the stability and control of the aircraft as well as mission functions. Some of the functions on the aircraft can be categorized as mission critical and loss of these functions could therefore keep the aircraft from completing its mission. More importantly, there are functions on the aircraft which are flight critical and loss of these functions would not only cause termination of the mission but also loss of the aircraft itself, especially when the aircraft is a fly-by-wire (FBW) aircraft.

The FTEPS program is a five-phase program as shown below:

Phase I - Load Study

Phase II - Analysis and Preliminary Design
- Task 1 - FTEPS Demonstrator Basic Requirements
- Task 2 - FTEPS Analysis, Trade-off Study, and Specific Requirements
- Task 3 - FTEPS Demonstrator Conceptual Design
- Task 4 - FTEPS Demonstrator Preliminary Design

Phase III - Detailed Design

Phase IV - Fabrication

Phase V - Testing and Reporting

The total length of the program is 42 months. This report documents the work done in Phase I - Load Study. The primary emphasis in Phase I was to define and characterize the electrical loads for an ATF class aircraft. Additionally, a conceptual layout of the ATF aircraft and the location of the electrical loads and equipment was prepared.

2.0 AIRCRAFT SYSTEM DESCRIPTION

The airplane configuration that has been selected for the baseline aircraft is the Model 908-833 (ref. 1). This 1989 Technology Availability Date (TAD) airplane is ideally suited for use in this program since it is designed to fulfill the mission requirements of the ATF class aircraft. Figure 2-1 shows a summary of the characteristics of the 908-833, including a 3-view of the airplane with principal dimensions.

This twin engine design is a high performance aircraft with a thrust-to-weight ratio of 1.25 to 1. It can operate throughout the flight envelope required for the ATF class aircraft. The wide speed and altitude range of this airplane are shown in Figure 2-2. The 908-833 incorporates canards, wing trailing edge surfaces, and 2-D vectorable and reversible nozzles for thrust and pitch control. Four flaperons, two leading edge flaps, two trailing edge flaps, twin rudders, and independently controlled and actuated canards are a part of the basic design. The actuation systems for the flight surfaces include electro-hydraulic pumps which constitute part of the high technology loads (HTL) for the FTEPS.

2.1 Avionics System

The avionics for the baseline aircraft is the PAVE PILLAR system (ref. 2). This system includes not just the mission avionics, but all the aircraft electronics - including flight control and propulsion. A diagram of the PAVE PILLAR system architecture is shown in Figure 2-3. This system is fault tolerant with system-level capabilities to detect faults, isolate failed modules, and recover from an intermittent module failure. A system goal is to operate 200 hrs. with 90% probability that no scheduled or unscheduled maintenance will be required. The entire avionics system is sized to provide 100% reserve capacity in processing throughout, memory, and bus traffic.

PAVE PILLAR improvements in system performance are obtained through the collective incorporation of several features in the avionics system: advanced subsystems, sensor sharing, information fusion, onboard digital map, selective automation, and an advanced crew station. Advanced integrated subsystems,

Model 908-833 1989 TAD Single Crew	
• Takeoff gross weight (TOGW) (lb)	40,000
• Flight design weight (FDWT) (lb)	36,000
• Propulsion type:	2 PWA STJ 562 A/B
• T/W at TOGW	1.25
• SLST A/B per eng (lb)	25,000
• Nozzle	2-D/reverser
• Inlet	2-D/fixed ramp
• Wing:	
• Area (trap)	571
• W/S at TOGW (lb/ft^2)	70
• AR	4.5
• Leading edge sweep (deg)	37.5
• Taper	0.25
• T/C	0.05/0.035
• Landing gear at TOGW	CBR 9, 50 passes

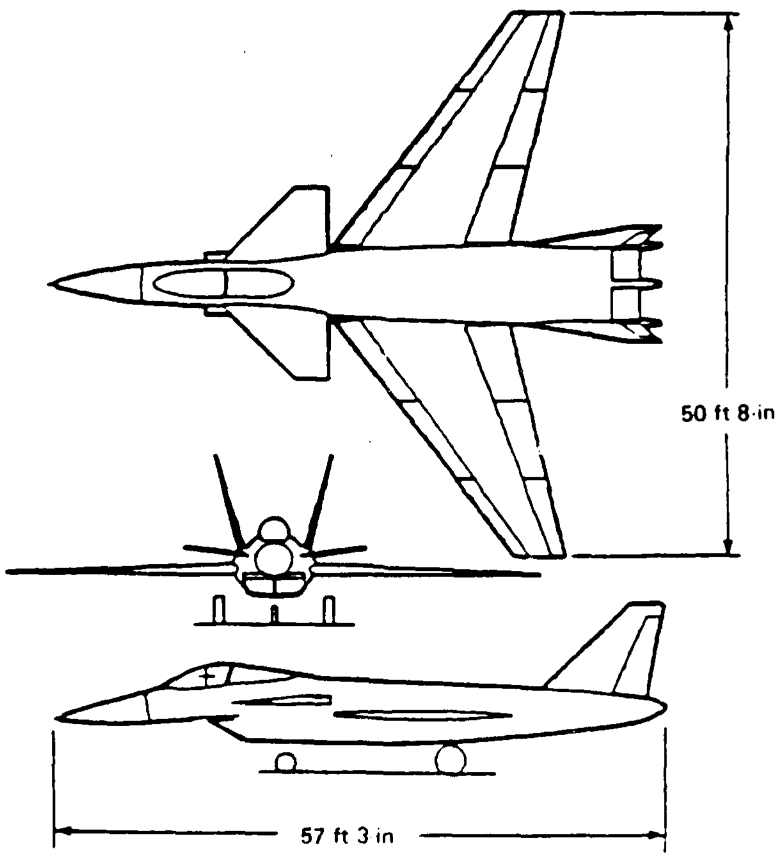


Figure 2-1: Model 908-833 General Arrangement

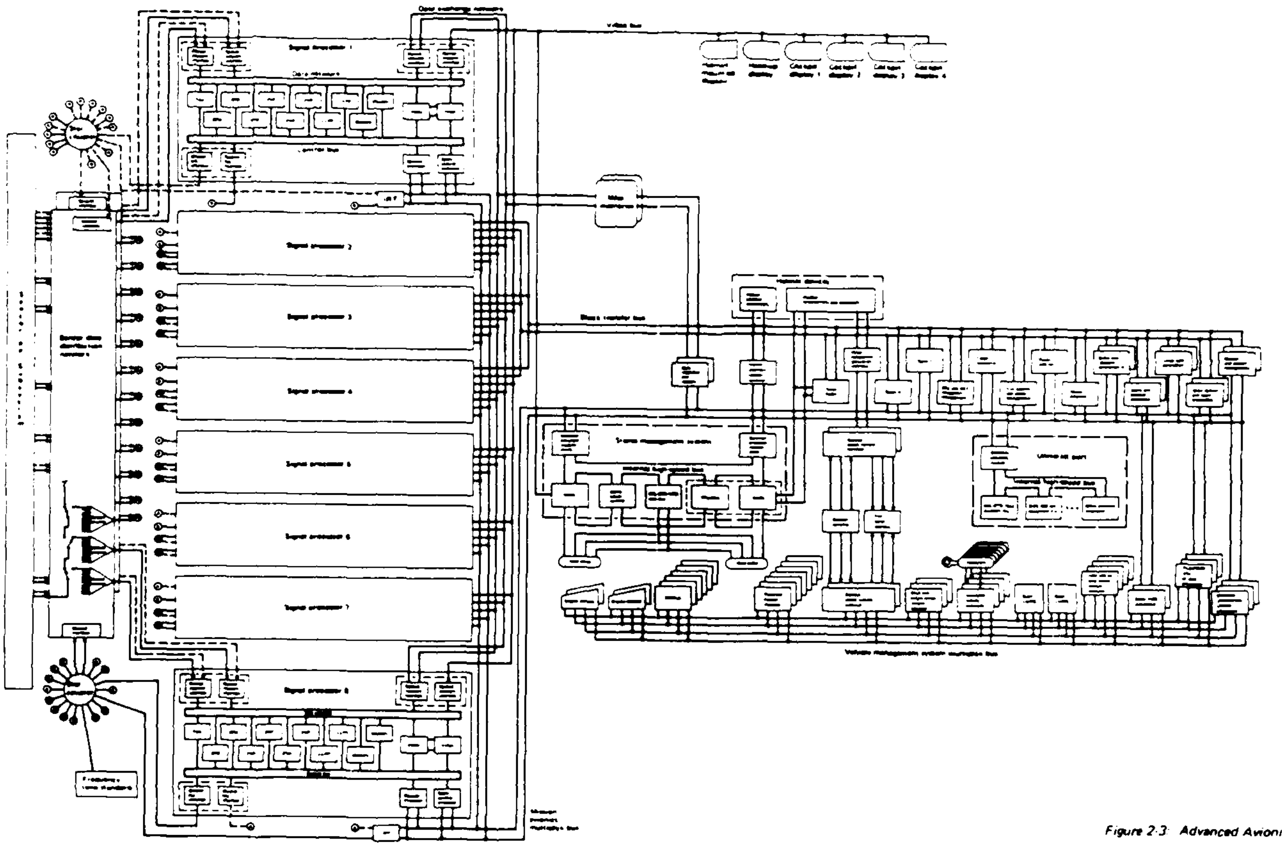


Figure 2-3. Advanced Avionics Architecture

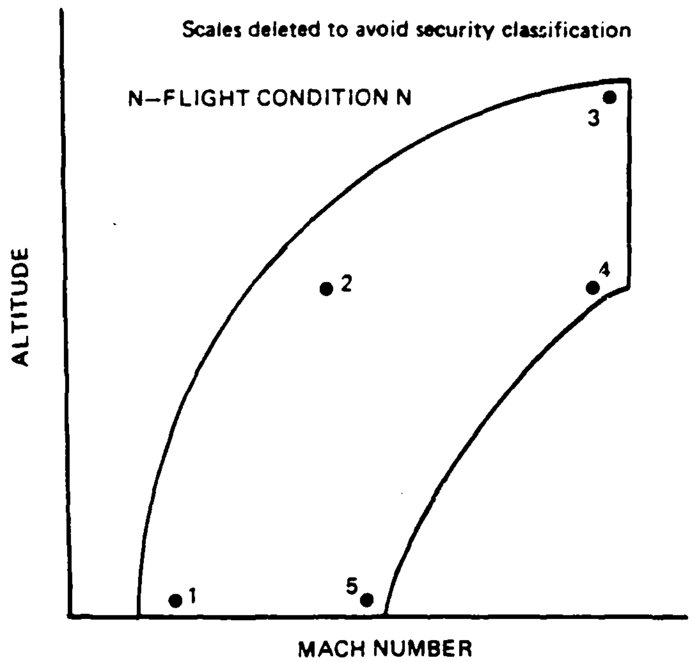


Figure 2-2: Flight Envelope

processors is organized as a resource pool, where every processor can perform any of the necessary data processing functions. The resource pool includes spare processors that can assume the duties of any failed data processor, thereby allowing the system to "fly-with-failures" with no loss in functional capability. Reconfiguration of the system following a processor failure (or later recovery) is done automatically, avoiding any interruption of the normal crew workload unless functional capability is lost. Advanced packaging techniques make the module accessible at the flightline, permit replacement of a failed component in the flightline environment, distribute power in a fault tolerant fashion, provide EMI/EMP protection, and keep the VHSIC/VLSI components at temperatures needed to ensure long life. This packaging concept is shown in Figure 2-4. The LRM's are contained in a series of integrated avionics racks which are liquid cooled and contain centralized power supplies. The signal processing for the mission sensors is pooled, much as for the data processors, in an integrated subsystem that can share programmable signal processing hardware among several sensor front ends. Control of the entire avionics systems is decentralized and shared among the data processors so that loss of a single processor has negligible effect on system operation. The ITM function summarizes the results of advanced testing techniques to provide maintenance data that speed the ground maintenance actions necessary to return a non-mission-capable aircraft to full mission capability.

2.2 Flight Control

The flight control system is digital fly-by-wire with a mix of hydraulic and electrical actuators. The digital processors are four channels, with the processors residing in the VMS avionics racks. The VMS, which is part of the PAVE PILLAR avionics system, is flight critical.

The flight control actuation system is shown in Figure 2-5. Hydraulic actuators are used for the leading edge flaps and the flaperons. The electrical actuators are integrated actuator packages (IAP) which are electric motor driven hydraulic pumps in a self-contained actuator package. A duplex IAP is used for each canard. A simplex IAP is used for each rudder and inboard trailing edge flap.

such as ICNIA and INEWS, provide increased functional capability for the system. Shared sensors allow a single sensor to provide data to several system functions, such as terrain following/terrain avoidance (TF/TA), target acquisition, or threat warning. Information fusion combines data from multiple sensors to achieve better results than can be obtained from any single sensor; sensor blending of terrain inputs permits more effective scene generation for safe penetration at low altitude, while fusion of target inputs from multiple sensors results in better target detection and classification rates with fewer false alarms. An onboard digital map allows route planning for areas outside sensor coverage, minimizes threat exposure by taking advantage of terrain shadowing, and improves stealthiness by allowing reduced use of active sensors for terrain imaging. Automation of certain time-critical functions, such as TF/TA and target acquisition ensures that the performance objectives can be met within the very short periods between the first acquisition of data and the point where a decision must be made. An advanced crew station featuring a highly automated cockpit, voice control, and pictorial display formats reduces the crew workload to a level that can be managed by one pilot.

PAVE PILLAR improvements in avionics availability are being achieved through the implementation of an architecture that (1) changes the primary maintenance element from a line replaceable unit (i.e., the black box) to a line replaceable module (LRM), (2) standardizes the LRM units, (3) uses a self-checking processing pair as a data processing LRM, (4) groups the data processors as a resource pool with spare units, (5) automatically reconfigures the system after a fault is recognized, (6) applies advanced packaging techniques to the LRM, (7) integrates and pools the signal processing components in sensor subsystems, (8) decentralizes system control, and (9) employs an integrated test and maintenance (ITM) function. The reduction in size of the line replaceable unit to a module or card level reduces module cost and allows use of a two-level maintenance concept in PAVE PILLAR. The data processor LRM is standardized so that an entire data processor is contained in a single module, thereby eliminating the need for a conventional processor backplane and dramatically reducing the number of connectors in the system. The data processor is designed as a self-checking pair to provide nearly perfect fault isolation if the processor fails. The entire set of data

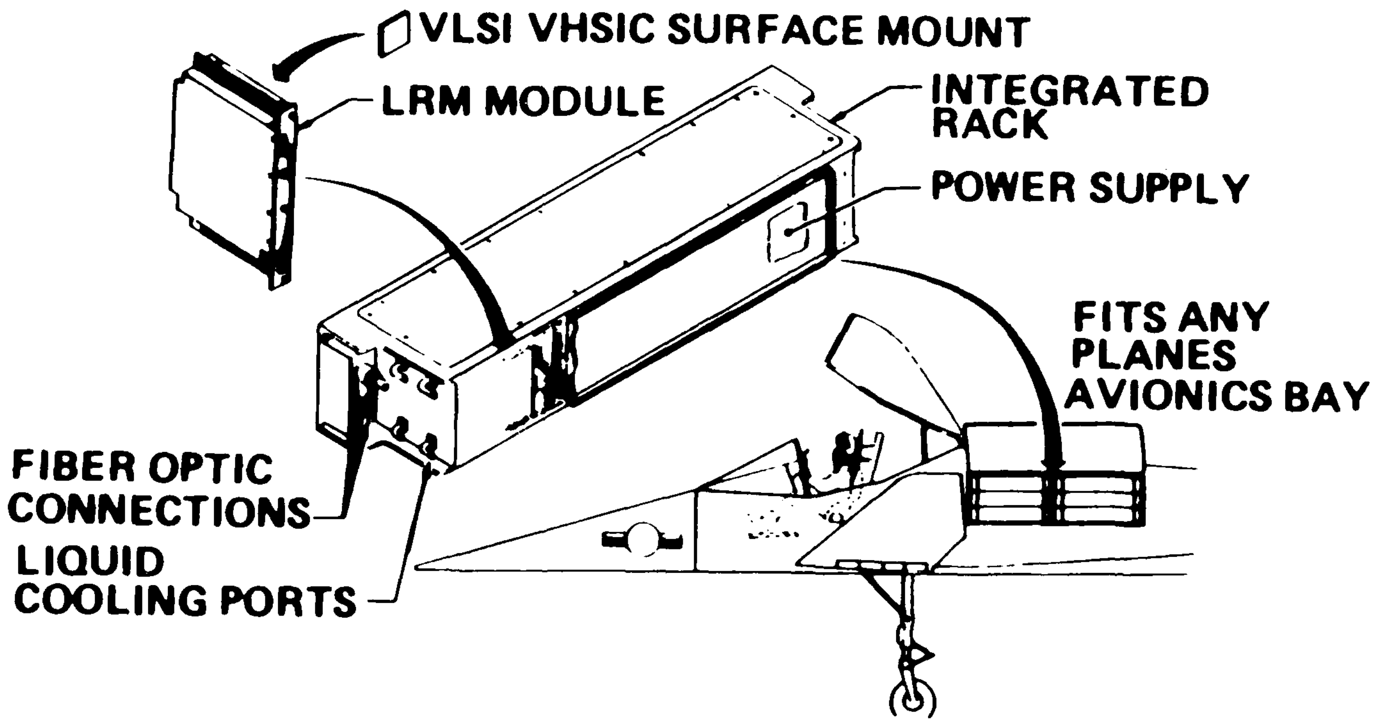


Figure 2-4: Integrated Avionics Rack

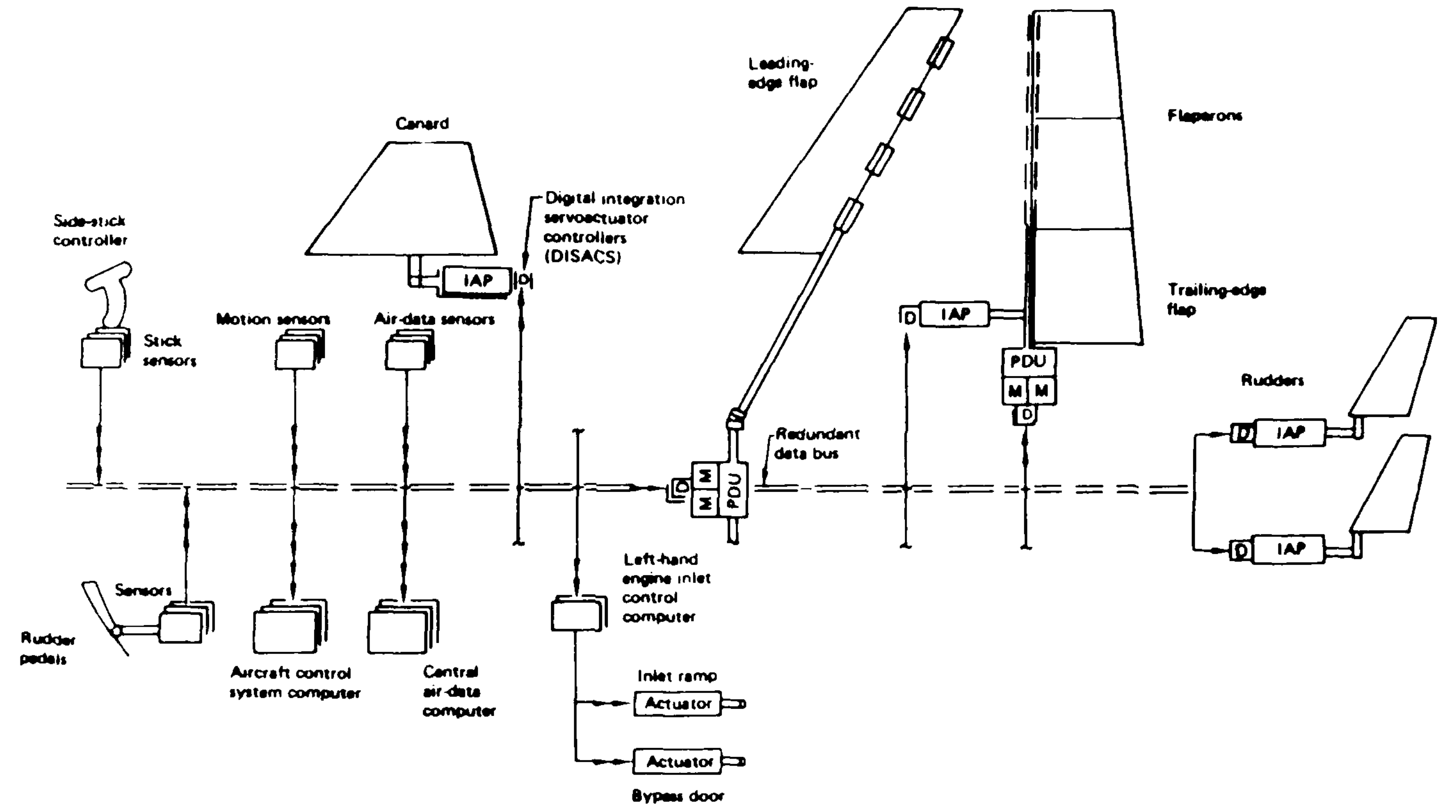


Figure 2-5: Flight Control Actuation System

The controls for the actuators are called Digital Integrated Servoactuator Controllers (DISAC) (ref. 3). The DISAC provides the data bus interface as well as the local control and redundancy management of the actuators. Each DISAC has the capability of controlling one or both halves of a dual redundant actuator.

2.3 Engine Control

An electronic engine control system is incorporated in the baseline aircraft as part of the VMS. A digital data bus is the control link to the engine. For each engine, there are three groups of loads, control module, effectors, and ignition. Power for the control modules and effectors are provided by the aircraft. Power for the ignition is provided by dedicated engine generators.

2.4 Fuel

The fuel system loads consist of two boost pumps and 5 transfer pumps. The boost pumps are always on. Only two of the 5 transfer pumps are on at a time. The boost and transfer pumps are not flight critical since the fuel can be gravity fed.

2.5 Environmental Control System

The environmental control system (ECS) uses a vapor cycle cooling system with two electric motor driven vapor cycle compressors. Two cooling loops are used, a liquid loop and an air loop. In addition to the vapor cycle compressors, other major ECS electrical loads are four coolant pumps (2 dual redundant sets) for the liquid loop and one loop compressor for the air loop.

2.6 Stores Management

The stores management system includes provisions for 8 MIL-STD-1760A store stations. The interface for each station will include only the primary interface and will not include the 270 VDC power lines. Each station will require a total of 4010 watts. Figure 2-6 shows the primary interface for a MIL-STD-1760A stores station.

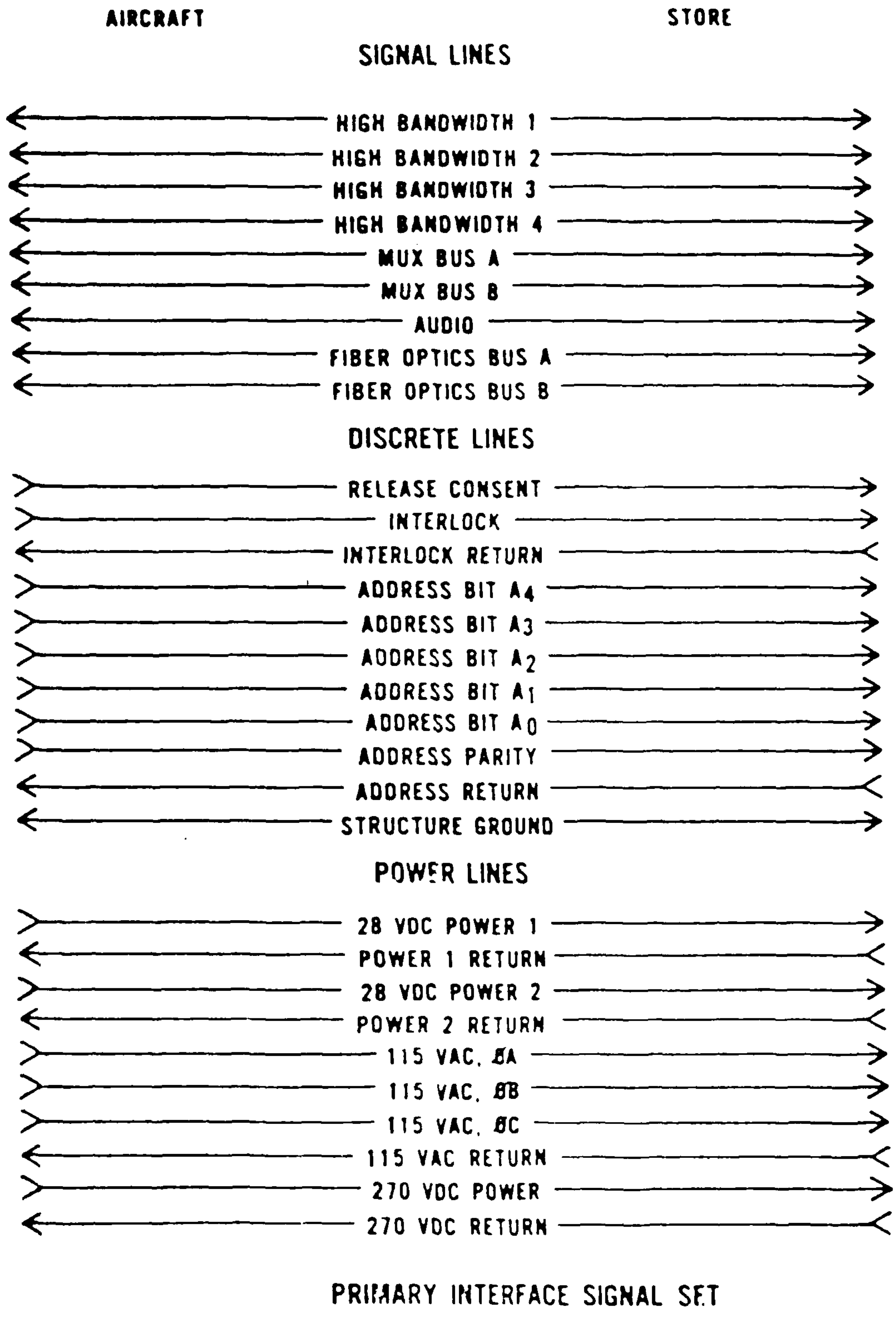


Figure 2-6. Primary Interface Signal Set

2.7 Secondary Power

The secondary power system, shown in Figure 2-7, is based on the use of the airframe mounted accessory drives (AMAD) and an integrated power unit (IPU). Through the series of clutches and shafts, each AMAD can be driven from either engine or the IPU. This arrangement also allows for engine start from the IPU or from the other engine if it is operating. Shaft driven accessories such as generators and hydraulic pumps are driven off of the AMADs. The IPU is an inflight operable auxiliary power unit which also functions as an emergency power source. In the emergency mode, the IPU can be started and be up to operating speed in 2 seconds. The configuration shown in Figure 2-7 shows a three generator system. This is one of the generator configurations to be trade studied in Phase II. The study will also include the four generator configurations shown in Figure 2-8.

2.8 High Technology Loads

High technology loads have been incorporated into the FTEPS load list. These include the electrically driven flight control actuators (see 2.2) and the electrically driven ECS (see 2.5). The actuators are called integrated actuator packages (IAP) which are electric motor driven hydraulic pumps in a self-contained actuator package. The load demand for the IAPs is shown in Table 2-1. These estimates are for the two duplex IAPs for the canard surfaces and the four simplex IAPs, one for each rudder and inboard trailing-edge flap. The power demands, expressed in horsepower from the electric motor shaft to the hydraulic pump, are based on the aerodynamic surface loads and rates.

The ECS consists of a vapor cycle cooling system which requires two 16 horsepower electrically driven compressors. In addition, the ECS requires 9.4 horsepower for the vapor compressor and 2.7 horsepower for each of four coolant pumps. These are all provided by electric motors.

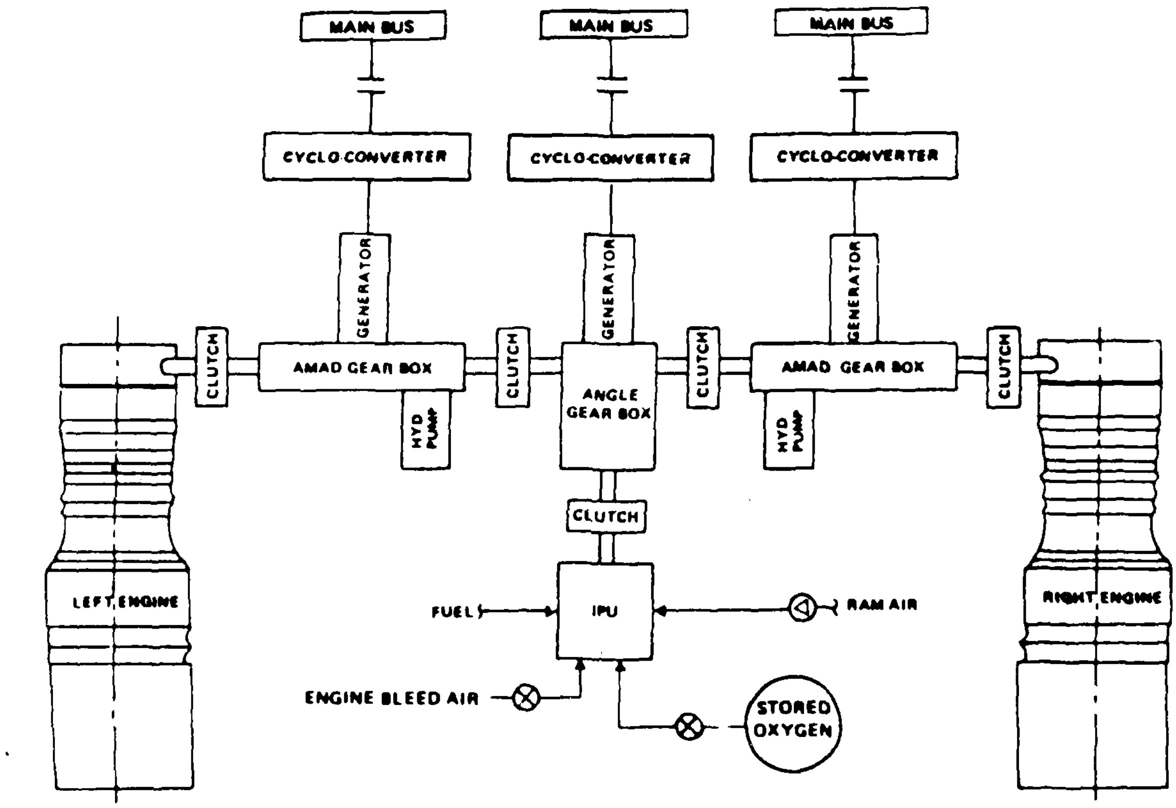


Figure 2-7: Secondary Power System with Three Generators

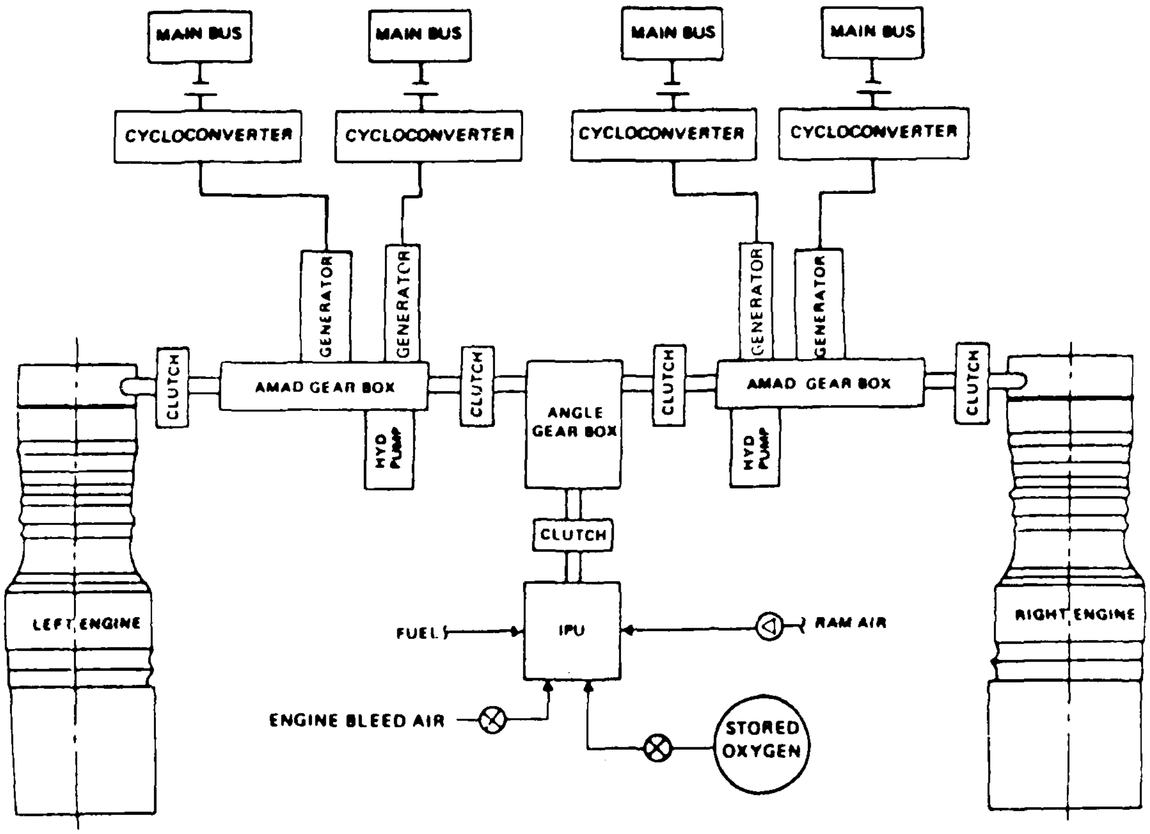


Figure 2-8: Secondary Power System with Four Generators

3.0 ELECTRICAL LOADS

A load complement has been compiled for the aircraft described in Section 2.0. The total connected load is 176,366 va. A listing of the loads are contained in Table 3-1. Many of the avionics loads are part of systems still in the development stage and no data was available on them. In these cases estimates were made on the power requirements and reliability based on similarity to existing equipment or "projections" by experienced design engineers. The loads were either 28VDC or 115VAC, 400 Hz.

3.1 Flight Critical Loads

Flight critical loads are those loads necessary for Level III flight. The VMS flight control digital processors, which are in the VMS integrated avionics racks, are quad redundant. Since the flight critical loads are redundant, a loss of an individual flight critical load does not result in the loss of the aircraft. Because of the sparing concept of the PAVE PILLAR system (ref. 2), the functional failure rate is much less than the hardware failure rate. The total load considered flight critical is 41,832 va, as shown in Table 3-2.

3.2 Mission Critical Loads

The majority of the aircraft loads are classified mission critical. These include the MAS integrated avionics racks and the sensor systems. Most mission equipment is hardware redundant or functionally redundant. The total load classified mission critical is 122,846 kva, as shown in Table 3-3.

3.3 Nonflight Critical Loads

Nonflight critical loads make up the smallest group of loads. The total load classified nonflight critical is 11,688 va.

3.4 Power Interruptions

For flight critical loads, the maximum tolerable power interruption for each load have been identified. These are shown in Table 3-1. The shortest

TABLE 2-1 INTEGRATED ACTUATOR PACKAGE MOTOR DEMAND

Operating Regime	Canard HIAPs (6.5-hp motor)		Rudder IAPs (5.4-hp motor)		Flap IAPs (2.3-hp motor)	
	Average Activity	Power Demand	Average Activity	Power Demand	Average Activity	Power Demand
Taxi	5%	1.25 hp	5%	1.04 hp	5%	0.45 hp
Climb	10%	1.52 hp	10%	1.27 hp	10%	0.55 hp
Dash	5%	1.25 hp	5%	1.04 hp	0%	0.35 hp
Combat	25%	2.35 hp	25%	1.96 hp	25%	0.85 hp
Return	5%	1.25 hp	5%	1.04 hp	5%	0.45 hp
Loiter	10%	1.52 hp	10%	1.27 hp	10%	0.55 hp

Table 3-1 Aircraft Load List

NO.	EQUIPMENT	MAX. CONNECTED LOAD, VA AC	DC	POWER FACTOR	PHASES	PROB. OF FAILURE	MTBF	LOC.	CLASS.	INTERRUPT TIME
	RADAR SENSOR SYSTEM									
1	ANTENNA	700		-0.9	3	2.0×10^{-3}	1,000	L1	MC	
2	TRANSMITTER	9000		-0.9	3	2.9×10^{-3}	700	L2	MC	
3	RECEIVER	700		-0.9	3	2.5×10^{-3}	800	L3	MC	
4	SIGNAL PROCESSOR	400		-0.9	3	4.0×10^{-4}	5,000	L4	MC	
	INEWS SENSOR SYSTEM									
5	RF WARNINGS&RANGE REC 1	100		-0.9	1	2.5×10^{-3}	800	L54	MC	
6	RF WARNINGS&RANGE REC 2	100		-0.9	1	2.5×10^{-3}	800	R55	MC	
7	RF WARNINGS&RANGE REC 3	100		-0.9	1	2.5×10^{-3}	800	R56	MC	
8	IR EO STARTING REC 1	100		-0.85	1	2.0×10^{-3}	1,000	L8	MC	
9	IR EO STARTING REC 2	100		-0.85	1	2.0×10^{-3}	1,000	L8	MC	
10	IR EO STARTING REC 3	100		-0.85	1	2.0×10^{-3}	1,000	L8	MC	
11	IR/EO STARTING REC 4	100		-0.85	1	2.0×10^{-3}	1,000	R58	MC	
12	IR EO STARTING REC 5	100		-0.85	1	2.0×10^{-3}	1,000	R58	MC	
13	IR EO STARTING REC 6	100		-0.85	1	2.0×10^{-3}	1,000	R58	MC	
14	IR EO TRACKING REC 1	100		-0.85	1	2.0×10^{-3}	1,000	L8	MC	
15	IR EO TRACKING REC 2	100		-0.85	1	2.0×10^{-3}	1,000	R58	MC	
16	FUSELAGE RF JAMMER	2,000		-0.9	3	2.9×10^{-3}	700	R53	MC	
17	WINGTIP RF JAMMER 1	2,000		-0.9	3	2.9×10^{-3}	700	T91	MC	
18	WINGTIP RF JAMMER 2	2,000		-0.9	3	2.9×10^{-3}	700	T92	MC	
19	TAIL RF JAMMER 1	2,000		-0.9	3	2.9×10^{-3}	700	T93	MC	
20	TAIL RF JAMMER 2	2,000		-0.9	3	2.9×10^{-3}	700	T94	MC	
21	IR JAMMER	2,000		-0.9	3	2.9×10^{-3}	700	R62	MC	
22	CHAFF DISPENSER		500			1.3×10^{-3}	1,500	L41	MC	

Table 3-1 Aircraft Load List (continued)

NO.	EQUIPMENT	MAX. CONNECTED LOAD, VA AC	DC	POWER FACTOR	PHASES	PROB. OF FAILURE	MTBF	LOC.	CLASS.	INTERRUPT TIME
	CNI SENSOR SYSTEM									
23	L-BAND RF	1000		-0.9	3	2.0×10^{-3}	1,000	L7	MC	
24	LOW BAND RF	1000		-0.9	3	2.0×10^{-3}	1,000	L7	MC	
25	L-BAND CSP I F UNIT	200		-0.9	3	5.0×10^{-3}	400	L7	MC	
26	LOW BAND CSP I F UNIT	200		-0.9	3	5.0×10^{-3}	400	L7	MC	
27	RADAR ALTIMETER	25		-0.9	1	1.4×10^{-3}	1,400	L6	MC	
28	CRYPTO UNIT	150		-0.9	3	2.0×10^{-4}	10,000	R63	MC	
29	IIRA IMU	200		1.0	1	2.0×10^{-3}	1,000	R43	MC	
30	IIRA IMU	200		1.0	1	2.0×10^{-3}	1,000	L5	MC	
	IRST SENSOR SYSTEM									
31	IR EO SENSOR 1	500		-0.9	3	2.5×10^{-3}	800	L39	MC	
32	IR EO SENSOR 2	500		-0.9	3	2.5×10^{-3}	800	L40	MC	
33	SENSOR CRYOGENIC UNIT 1	800		-0.9	3	2.5×10^{-3}	800	L16	MC	
34	SENSOR CRYOGENIC UNIT 2	800		-0.9	3	2.5×10^{-3}	800	R44	MC	
35	IR CSP I F UNIT	400		-0.9	3	5.0×10^{-3}	400	L17	MC	
	INFORMATION MANAGEMENT									
36	HUD	225		-0.9	1	1.0×10^{-3}	2,000	L12	MC	
37	MULTI-FUNC DISPLAY 1	250		-0.9	1	1.0×10^{-3}	2,000	L12	MC	
38	MULTI-FUNC DISPLAY 2	250		-0.9	1	1.0×10^{-3}	2,000	L12	MC	
39	MULTI-FUNC DISPLAY 3	250		-0.9	1	1.0×10^{-3}	2,000	L12	MC	
40	INTEGRATED KEYBOARD	65		-0.9	1	1.0×10^{-4}	20,000	L12	MC	

Table 3-1 Aircraft Load List (continued)

NO.	EQUIPMENT	MAX. CONNECTED LOAD, VA AC	MAX. CONNECTED LOAD, VA DC	POWER FACTOR	PHASES	PROB. OF FAILURE	MTBF	LOC.	CLASS.	INTERRUPT TIME
41	FLAT PANEL-UPPER	30		-0.9	1	1.0×10^{-3}	2,000	L12	MC	
42	FLAT PANEL-LOWER	15		-0.9	1	1.0×10^{-3}	2,000	L12	MC	
43	DATA TRANSFER UNIT 1	20		-0.9	1	3.3×10^{-4}	6,000	L11	MC	
44	DATA TRANSFER UNIT 2	20		-0.9	1	3.3×10^{-4}	6,000	R45	MC	
	SIGNAL PROCESSORS									
45	RACK 1	500		-0.9	3	*	*	L13	MC	
46	RACK 2	500		-0.9	3	*	*	L14	MC	
47	RACK 3	500		-0.9	3	*	*	R46	MC	
48	RACK 4	500		-0.9	3	*	*	R47	MC	
49	RACK 5	500		-0.9	3	*	*	L21	MC	
50	RACK 6	500		-0.9	3	*	*	L22	MC	
51	RACK 7	500		-0.9	3	*	*	R48	MC	
52	RACK 8	500		-0.9	3	*	*	R49	MC	
53	POWER SUPPLY 1	600		-0.9	3	2.9×10^{-4}	7,000	L25	MC	
54	POWER SUPPLY 2	600		-0.9	3	2.9×10^{-4}	7,000	R50	MC	
	MISSION AVOINICS SYSTEM RACKS									
55	MAS RACK 1	450		-0.9	3	2.9×10^{-4}	7,000	L10	MC	
56	MAS RACK 2	450		-0.9	3	2.9×10^{-4}	7,000	L19	MC	
	VEHICLE MANAGEMENT SYSTEM RACKS									
57	VMS RACK 1	500		-0.9	3	2.9×10^{-4}	7,000	L9	FC	50 uSEC
58	VMS RACK 2	500		-0.9	3	2.9×10^{-4}	7,000	L15	FC	50 uSEC
59	VMS RACK 3	500		-0.9	3	2.9×10^{-4}	7,000	L20	FC	50 uSEC
60	VMS RACK 4	500		-0.9	3	2.9×10^{-4}	7,000	R52	FC	50 uSEC
61	MASS MEMORY UNIT	200		-0.9	1	8.0×10^{-4}	2,500	R61	MC	

Table 3-1 Aircraft Load List (continued)

NO.	EQUIPMENT	MAX. CONNECTED LOAD, VA AC	DC	POWER FACTOR	PHASES	PROB. OF FAILURE	MTBF	LOC.	CLASS.	INTERRUPT TIME
	ENGINE CONTROLS									
62	ELEC CONTROL UNIT 1A		100			1.0×10^{-3}	2,000	L76	FC	50 uSEC
63	ELEC CONTROL UNIT 1B		100			1.0×10^{-3}	2,000	L76	FC	50 uSEC
64	ELEC CONTROL UNIT 2A		100			1.0×10^{-3}	2,000	R75	FC	50 uSEC
65	ELEC CONTROL UNIT 2B		100			1.0×10^{-3}	2,000	R75	FC	50 uSEC
	SECONDARY POWER									
[illegible]	GOX COMPRESSOR	750		-0.8	3	2.9×10^{-3}	700	L27	NFC	
	FUEL INERTING									
67	MS100 GAS SEPARATOR	58	84	-0.8	1	2.4×10^{-4}	8,400	R64	NFC	
68	HIGH PRESSURE COMPRESS	6000		-0.8	3	2.0×10^{-3}	1,000	R64	NFC	
69	BOOST COMPRESS	2200		-0.8	3	4.0×10^{-4}	5,000	R64	NFC	
	FUEL SYSTEM									
	MAX INFLIGHT LOADS ONLY TWO TRANSFER PUMPS ON AT A TIME									
70	LEFT BOOST PUMP	6400		-0.8	3	4.0×10^{-4}	5,000	L33	MC	
71	RIGHT BOOST PUMP	6400		-0.9	3	4.0×10^{-4}	5,000	R65	MC	
72	TRANSFER PUMP 1	1600		-0.8	3	2.9×10^{-5}	68,000	T34	MC	
73	TRANSFER PUMP 2	1600		-0.8	3	2.9×10^{-5}	68,000	T35	MC	
74	TRANSFER PUMP 3	1600		-0.8	3	2.9×10^{-5}	68,000	T36	MC	
75	TRANSFER PUMP 4	1600		-0.8	3	2.9×10^{-5}	68,000	T37	MC	
76	TRANSFER PUMP 5	1600		-0.8	3	2.9×10^{-5}	68,000	T38	MC	
[illegible]	FUEL QUANTITY	26		1.0	1	1.7×10^{-3}	1,200	R80	MC	
78	FUEL FLOW	23		-0.9	1	2.0×10^{-3}	1,000	L78	MC	

Table 3-1 Aircraft Load List (continued)

NO.	EQUIPMENT	MAX. CONNECTED LOAD, VA AC	DC	POWER FACTOR	PHASES	PROB. OF FAILURE	MTBF	LOC.	CLASS.	INTERRUPT TIME
	FLIGHT CONTROL ACTUATION									
79	L CANARD IAP 1	4847		-0.8	3	1.2×10^{-4}	16,000	L23	FC	2 SEC
80	L CANARD IAP 2	4847		-0.8	3	1.2×10^{-4}	16,000	L24	FC	2 SEC
81	R CANARD IAP 1	4847		-0.8	3	1.2×10^{-4}	16,000	R66	FC	2 SEC
82	R CANARD IAP 2	4847		-0.8	3	1.2×10^{-4}	16,000	R67	FC	2 SEC
83	L RUDDER IAP	4027		-0.8	3	1.2×10^{-4}	16,000	L29	FC	2 SEC
84	R RUDDER IAP	4027		-0.8	3	1.2×10^{-4}	16,000	R69	FC	2 SEC
85	L FLAP IAP	1715		-0.8	3	1.2×10^{-4}	16,000	L28	FC	2 SEC
86	R FLAP IAP	1715		-0.8	3	1.2×10^{-4}	16,000	R68	FC	2 SEC
87	14 DISACS (40 EA,DC)		560			1.2×10^{-4}	16,000	26	FC	500 mSEC
	LIGHTING & MISCELLANEOUS									
88	LIGHTING	1231		-0.9	1	2.0×10^{-3}	1,000	L42	NFC	
89	SEAT ADJUST		500			4.0×10^{-4}	5,000	L32	NFC	
	STORES MANAGEMENT									
	STATION 1									
90	DC 1		280			5.0×10^{-4}	4,000	T83	MC	
91	DC 2		280			5.0×10^{-4}	4,000	T83	MC	
92	AC	3450		-0.9	3	5.0×10^{-4}	4,000	T83	MC	
	STATION 2									
93	DC 1		280			5.0×10^{-4}	4,000	T84	MC	
94	DC 2		280			5.0×10^{-4}	4,000	T84	MC	
95	AC	3450		-0.9	3	5.0×10^{-4}	4,000	T84	MC	

Table 3-1 Aircraft Load List (continued)

NO.	EQUIPMENT	MAX. CONNECTED LOAD, VA AC	DC	POWER FACTOR	PHASES	PROB. OF FAILURE	MTBF	LOC.	CLASS.	INTERRUPT TIME
	STATION 3									
96	DC 1		280			5.0×10^{-4}	4,000	T85	MC	
97	DC 2		280			5.0×10^{-4}	4,000	T85	MC	
98	AC	3450		-0.9	3	5.0×10^{-4}	4,000	T85	MC	
	STATION 4									
99	DC 1		280			5.0×10^{-4}	4,000	T86	MC	
100	DC 2		280			5.0×10^{-4}	4,000	T86	MC	
101	AC	3450		-0.9	3	5.0×10^{-4}	4,000	T86	MC	
	STATION 5									
102	DC 1		280			5.0×10^{-4}	4,000	T87	MC	
103	DC 2		280			5.0×10^{-4}	4,000	T87	MC	
104	AC	3450		-0.9	3	5.0×10^{-4}	4,000	T87	MC	
	STATION 6									
105	DC 1		280			5.0×10^{-4}	4,000	T88	MC	
106	DC 2		280			5.0×10^{-4}	4,000	T88	MC	
107	AC	3450		-0.9	3	5.0×10^{-4}	4,000	T88	MC	
	STATION 7									
108	DC 1		280			5.0×10^{-4}	4,000	T89	MC	
109	DC 2		280			5.0×10^{-4}	4,000	T89	MC	
110	AC	3450		-0.9	3	5.0×10^{-4}	4,000	T89	MC	
	STATION 8									
111	DC 1		280			5.0×10^{-4}	4,000	T90	MC	
112	DC 2		280			5.0×10^{-4}	4,000	T90	MC	
113	AC	3450		-0.9	3	5.0×10^{-4}	4,000	T90	MC	

Table 3-1 Aircraft Load List (continued)

NO.	EQUIPMENT	MAX. CONNECTED LOAD, VA AC	DC	POWER FACTOR	PHASES	PROB. OF FAILURE	MTBF	LOC.	CLASS.	INTERRUPT TIME
	TACTICAL LIFE SUPPORT SYSTEM									
114	BREATHING SYSTEM		35			1.4×10^{-3}	1,400	L18	MC	
115	FILTER BLOWER SYSTEM		23			4.0×10^{-5}	50,000	L18	MC	
116	ANTI-G VALVE		56			2.9×10^{-4}	7,000	L16	MC	
117	OCCULAR PROTECT		3			6.7×10^{-4}	3,000	L18	MC	
118	PERSONAL THERMAL CONT	865		-0.8	3	2.8×10^{-4}	7,100	L18	NFC	
	ENVIRONMENTAL CONTROL SYSTEM									
119	AVIONICS LOOP COMPRESSOR	7000		-0.8	3	8.0×10^{-5}	25,000	L31	MC	
120	COOLANT PUMP 1A	2000		-0.8	3	8.0×10^{-5}	25,000	R71	FC	2 SEC
121	COOLANT PUMP 1B	2000		-0.8	3	8.0×10^{-5}	25,000	R71	FC	2 SEC
122	COOLANT PUMP 2A	2000		-0.8	3	8.0×10^{-5}	25,000	R71	FC	2 SEC
123	COOLANT PUMP 2B	2000		-0.8	3	8.0×10^{-5}	25,000	R71	FC	2 SEC
124	MISC. FANS	1000		-0.8	3	1.3×10^{-4}	15,000	R72	MC	
125	VAPOR CYCLE COMPRESSOR 1	12,000		-0.8	3	1.7×10^{-4}	12,000	L30	MC	
126	VAPOR CYCLE COMPRESSOR 2	12,000		-0.8	3	1.7×10^{-4}	12,000	R30	MC	

Table 3-2 Flight Critical Loads

	Connected	Uninterrupted
VMS racks	2000 VA	2000 VA
Engine controls	400	400
ECS	8000	0
Flight control actuation *	31432	0
Total	41832 VA	2400 VA

* Actual operational load = 7696 VA

Table 3-3 Mission Critical Loads

	Connected	Uninterruptible
Radar sensor	10800 VA	
INEWS	13600	
CNI	2975	
IRST	3000	
Information management	1125	
MAS racks	900	900
Signal processor racks	5200	5200
Mass memory unit	200	
Fuel system (1)	20849	
ECS	32,000	
TLSS	117	
Stores (2)	32080	
Total	122,846 VA	6100 VA

(1) Actual operational load = 16000 VA
(2) Actual operational load = 8020 VA

4.0 AIRCRAFT CONCEPTUAL LAYOUT

The equipment identified in the load study includes all major equipment required for an ATF Type Vehicle. This equipment has been assigned specific locations on the baseline ATF Vehicle Configuration layout shown in Figure 2-1. The equipment and equipment racks were considered to be consistent with the integrated rack concepts being developed for next generation air vehicles. These racks emphasize modularity, maintainability, reliability and fault tolerance.

The primary equipment categories defined for the ATF vehicle used in this study are described in the following paragraphs and shown in Figures 4-1, 4-2 and 4-3. The conceptual layout shown in these figures provides a first-cut idea of how the equipment defined in the load study will be located in the vehicle. Changes to these drawings are anticipated as the preliminary and detailed designs are developed.

Major concerns in locating the equipment included size and space available, proximity requirements to user equipment or cockpit, and separability requirements for redundancy.

The major equipment categories are (See Table 4-1):

A) The Radar System which includes items L1, L2, L3 and L4.

B) The INEWS Sensor System which includes items L8, L41, L54, R52, R56, R58, T90, T91, T92 and T93.

C) The CNI Sensor System which includes items L7, L6, L5, R43, and R63.

D) The IRST Sensor System which includes items 39, 40, L16, L17 and R44.

E) The Information Management System which includes those items labeled L12, L11 and R45.

interruption time is 50 microseconds for the VMS integrated avionics racks which contain digital processors used for flight controls. Although not flight critical, the MAS and signal processor integrated avionics racks also have maximum tolerable power interruption times of 50 microseconds. The electronic control unit for the engine controls also has a power interruption time of 50 microseconds. The longest allowable interruption time is 2 seconds for the IAPs. In Phase II, methods for providing power, which has an interruption time of 50% shorter than the maximum allowed for each load, will be developed. For the shorter time, such as 50 microseconds, uninterruptible power may be required due to limitations of the hardware available for performing power transfers.

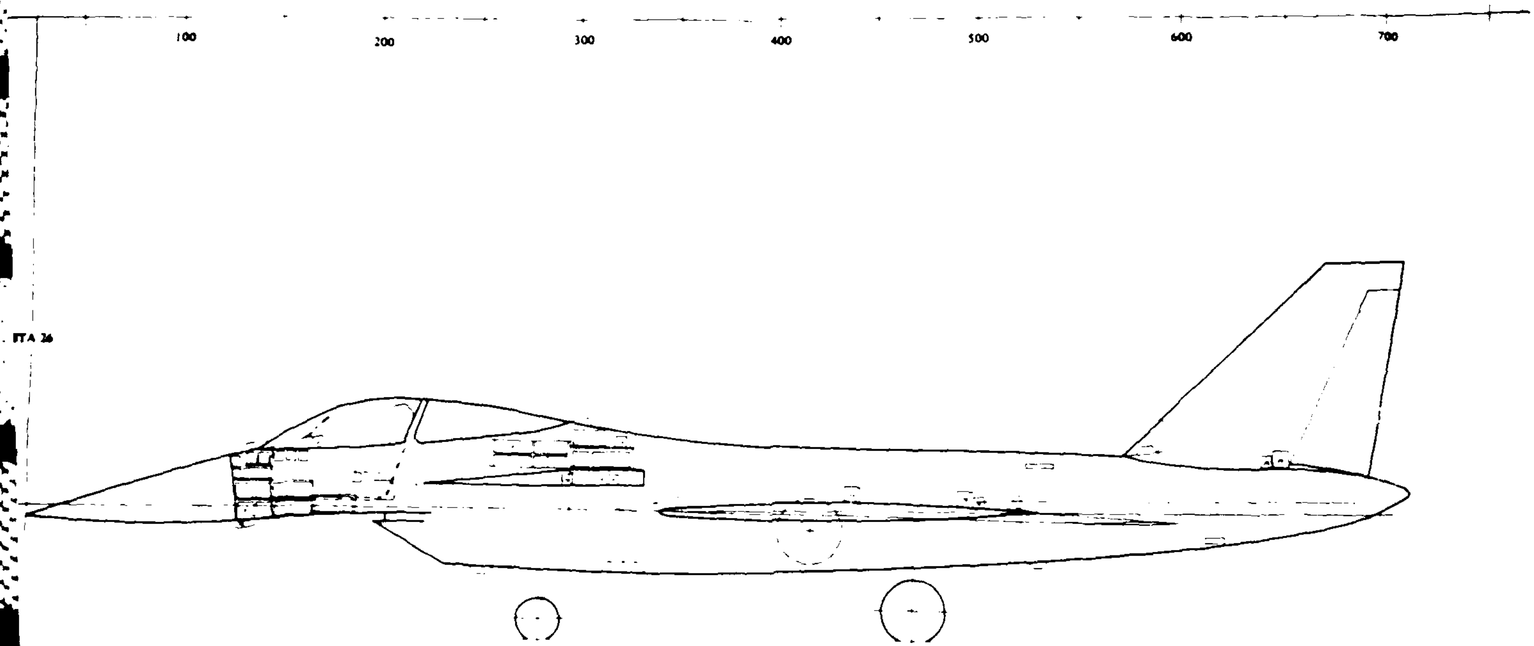
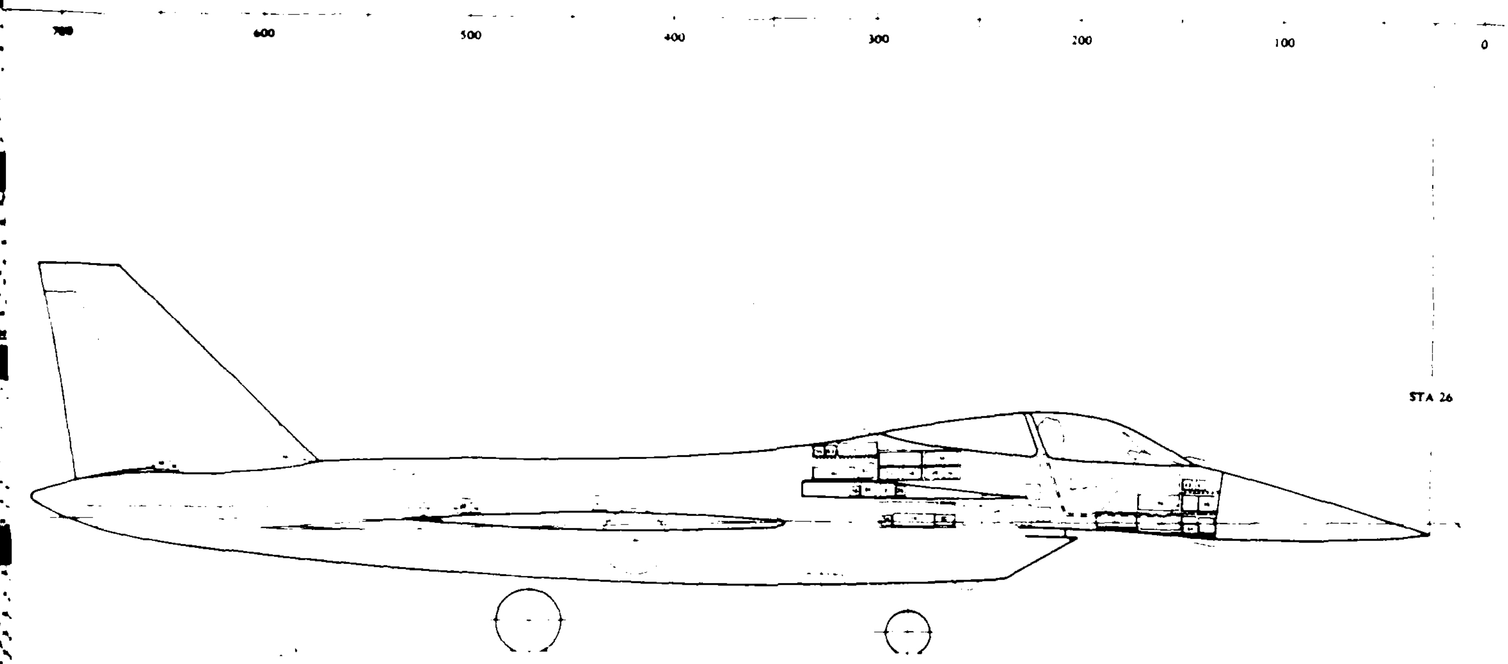


Figure 4-1: ATF Baseline Left Profile

ATF MODEL

EQUIPMENT LOCATIONS

E 81205 FTEPS-1



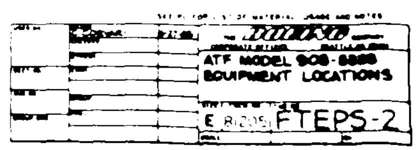


Figure 4-2 ATF Baseline Right Profile

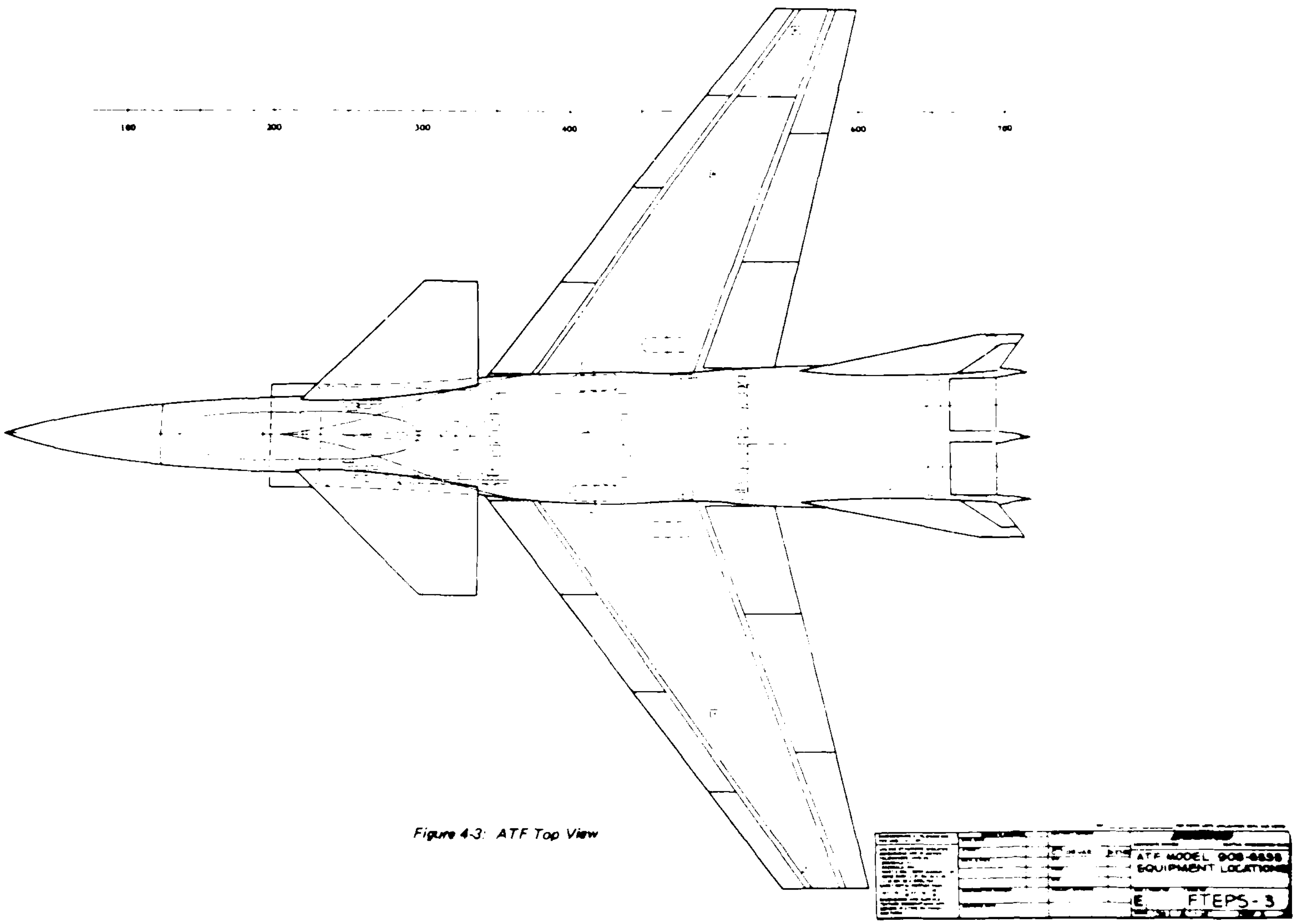


Figure 4-3: ATF Top View

TABLE 4-1

EQUIPMENT LOCATION LIST

#	Nomenclature	Location Bay	Station #
L1	Radar Antenna	Nose	100
L2	Radar Transmitter	FWD Eq. Bay(Upper)	140
L3	Radar Receiver	FWD Eq. Bay	140
L4	Radar Signal Processor	FWD Eq. Bay	140
L5	IIRA/IMN #1	FWD Eq. Bay	140
L6	Radar Altimeter	FWD Eq. Bay	140
L7	CNI Low Band/LBand Sensors	FWD Eq. Bay	140
L8	Starting Receivers #1, #2, #3		
	Tracking Receiver #1	FWD Eq. Bay	140
L9	VMS Rack #1	FWD Eq. Bay	140
L10	MAS Rack #1	FWD Eq. Bay	140
L11	Data Transfer Unit #1	FWD Left Cockpit	140
L12	HUD	Cockpit	175
	Multifunction Display #1, #2, #3		
	Keyboard		
	Flat Panel (Upper and Lower)		
L13	Signal Processor Rack #1	AFT Equip. Bay #2	310
L14	Signal Processor Rack #2	Lower Cockpit Bay	175
L15	VMS Rack #2	Lower Cockpit Bay	175
L16	Sensor Cryogenic Unit #1	FWD Cockpit	175
L17	IR CSP I/F Unit	FWD Cockpit	175
L18	Tactical Life Support System	Aft of Cockpit	210
	Breathing System		
	Filter Blower Sys./		
	Personal Thermal Cont.		
	Anti-G Value/Occular Protect		

TABLE 4-1

EQUIPMENT LOCATION LIST (continued)

# Nomenclature	Location/Bay	Station #
L19 MAS Rack #2	Aft Eq. Bay #1	280
L20 VMS Rack #3	A. Eq. Bay #1	280
L21 Signal Processor Rack #5	A. Eq. Bay #1	280
L22 Signal Processor Rack #6	A. Eq. Bay #1	280
L23 L Canard IAP #1	Root Left Canard	300
L24 L Canard IAP #2	Root Left Canard	300
L25 Signal Processor Pwr. Sup. Rk. #1	A. Eq. Bay #2	310
L26 DISACS	Locate near each IAP	---
L27 GOX Compressor	A. Eq. Bay #2	310
L28 L Flap IAP	Aft Root Left Wing	500
L29 L Rudder IAP	Lower Rudder Aft. Tail	640
L30/R30 Vapor Cycle Machine #1, #2	Aft of Cockpit	210
L31 Loop Compressor	Aft of Cockpit	210
L32 Seat Adjust	Left Cockpit	200
L33 Left Boost Pump	Left Midfuselage	450
T34 Transfer Pump #1	Left Wing	475
T35 Transfer Pump #2	Left Wing	400
T36 Transfer Pump #3	Mid Fuselage	400
T37 Transfer Pump #4	Right Wing	400
T38 Transfer Pump #5	Right Wing	475
L39 IR/EO Sensor #1	FWD Upper	140
L40 IR/EO Sensor #2	FWD Lower	140
L41 Chaff Dispenser	Lower AFT Fuselage	600
L42 Lighting Group	---	---

TABLE 4-1

EQUIPMENT LOCATION LIST (continued)

#	Nomenclature	Location/Bay	Station #
R43	IIRA/IMU	FWD Eq. Bay	140
R44	Sensor Cryogenic Unit #2	FWD Eq. Bay	140
R45	Data Transfer Unit #2	FWD Eq. Bay	140
R46	Signal Processor Rack #3	Lower Cockpit Bay	160
R47	Signal Processor Rack #4	Lower Cockpit Bay	160
R48	Signal Processor Rack #7	Aft. Equip. Bay #1	260
R49	Signal Processor Rack #8	Aft. Equip. Bay #1	260
R50	Signal Processor Pwr Supply #2	Aft. Equip. Bay #1	260
R52	VMS Rack #4	Aft. Eq. Bay #1	275
R53	Fuselage RF Jammer/IR Jammer	Aft. Eq. Bay #1	275
L54	RF Warning Rec #1	AFT Eq. Bay #2	310
R55	RF Warning & Range Dec. #2	Aft. Eq. Bay #2	325
R56	RF Warning & Range Dec. #3	Lower Aft. Eq. Bay	290
R57	ELMC Rack #1	Lower Cockpit Bay	190
R58	IR/ED Starting Rec #4, #5, #6 IR/EO Tracking Rec. #2	Fwd. Equip. Bay	140
R59	ELMC Rack #2	Lower Aft. Equip. Bay	325
R60	ELMC Rack #3	Aft. Equip. Bay #2	325
R61	VMS Mass Memory Unit	Aft. Equip. Bay #2	325
R62	INEWS IR Jammer	Aft. Equip. Bay #2	325
R63	CNI Crypto Unit	Aft. Equip. Bay #2	325
R64	Fuel Inerting System	Aft. Cockpit	240
R65	Right Fuel Boost Pump	Mid Fuselage Right	450
R66	Right Canard IAP #1	Root Right Canard	300
R67	Right Canard IAP #2	Root Right Wing	500

TABLE 4-1

EQUIPMENT LOCATION LIST (continued)

#	Nomenclature	Location/Bay	Station #
R68	Right Flap IAP	Roof of Right Wing	500
R69	Right Rudder IAP	Root of Right Rudder	640
L70	ELMC Rack #4	Lower Cockpit Bay	160
R71	ECS Pumps #1A,B; #2A,B	Aft. Cockpit	250
R72	ECS Fans	Aft. Cockpit	225
R75	Engine Control Unit #2A,B	Aft. Fuselage	530
L76	Engine Control Unit #1A,B	Aft. Fuselage	530
L78	Fuel Flowset	Aft. Fuselage	530
L80	Fuel Quantity Set	Lower Aft. Equip. Bay	275
T81	Electrical Generators (4)	Fwd. Engine	520
T82	APU Generator	Fwd. Engine	520
T83	Stores Management Station #1	Mid Fuselage	350
T84	--- #2	---	---
T85	--- #3	---	---
T86	--- #4	---	---
T87	--- #5	---	---
T88	--- #6	---	---
T89	--- #7	---	---
T90	--- #8	---	---
T91	Wingtip Jammer #1	Right Wingtip	550
T92	Wingtip Jammer #2	Left Wingtip	550
T93	Tail Jammer #1	Left Tail	675
T94	Tail Jammer #2	Right Tail	675

F) The Signal Processor System which includes items L13, L14, L21, L22, L25, R46, R47, R48, R49 and R50.

G) The Mission Avionics System which includes items L10 and L19.

H) The Vehicle Management System which includes items L9, L15, L20, R53, and R61.

I) The Engine Controls which includes items L75, L77, L78, R76, R79 and R80.

J) The Secondary Power System which includes items L27, L57, L70, R59, R60, T81 and T82.

K) The Fuel Inerting System which includes those items designated R64.

L) The Fuel System which includes items L33, T34, T35, T36, T37, T38 and R65.

M) Lighting and Miscellaneous items which include L32 and L42.

N) The Stores Management System which includes items T83, T84, T85, T86, T87, T88, T89 and T90.

O) The Flight Control Actuation System which includes items L23, L24, L28, L29, R66, R67, R68 and R69.

P) The Tactical Life Support System which includes items designated L18.

Q) The Environmental Control System which includes items L30, L31, R71 and R72.

5.0 RESULTS AND CONCLUSIONS

A model of an ATF aircraft was selected. The loads have been located in the model aircraft. This will be used to prepare the physical layout of the electrical generation and distribution system.

A load list for the ATF baseline aircraft was completed. The total load for the aircraft is 176 kva of which 6.6 kw has been identified as DC loads. The loads have been categorized flight critical, mission critical and nonflight critical. The length of power interruptions which each flight critical load can withstand was identified. For the VMS and MAS, integrated avionics racks, which perform the digital processing for flight and mission functions, the maximum power interruption is 50 microseconds.

For each load, a MTBF number has been assigned. This number will be used to calculate the probability of failure for each load (based on a 2 hour mission length). Power, which has a probability of failure 100 times less than the probability of failure of the load itself, will be delivered to each load.

For the flight critical loads, maximum tolerable power interruption times have been identified. These times range from 50 microseconds for the VMS integrated avionics racks which contain the flight control digital processors to 2 seconds for the flight control IAPs.

Two high technology loads have been identified for the ATF baseline. These are the IAPs and the electric motor driven vapor cycle machines.

6.0 RECOMMENDATIONS

A baseline aircraft and a load complement have been established. The loads have been located in the aircraft. The data has been developed which is required to perform Phase II, Analysis and Preliminary Design of the FTEPS Demonstrator. It is therefore recommended that the program be allowed to proceed into Phase II.

REFERENCES

1) D180-28576-1, Fault Tolerant Electrical Power System, Technical Proposal, Boeing Co., November 1984.

2) AFWAL-TR-84-1193, Advanced System Integration Demonstrators (ASID) System Definition, August 1984.

3) D180-26981-1, Specification for Digital Integrated Servoactuator Controller (DISAC) for Reconfigurable Fly-By-Wire Actuation System, May 1982.

END

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DTIC